Consequences for the design of military aircraft systems due to integration of commercial electronic components in avionics

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1. SUMMARY

The time when aerospace requirements and investments initiated micro-electronic components development has passed.

Industries like Telecom and Personal Computer invest many times more than aerospace with huge economical, performance, size, mass, packaging and assembly improvements.

The lifespan of these developments in the market is very short.

The Life Cycle Costs for keeping up avionics design with special ruggidised components and designs is likely to be higher than to adapt a military aircraft and their periphery to avionics with non-ruggid electronic components.

There are technical solutions available to adapt the military avionics environment to the requirements of non-ruggid electronic components ad designs.

This paper describes the relevant environmental aspects in nowadays military aircraft designs, which have to be considered and their relation to non-ruggid electronics.

Further on this paper describes some possible modifications of military aircraft designs to cope with the environmental requirements of non-ruggid electronics.

2. ADVANTAGES OF USING UNSCREENED ELECTRONIC COMPONENTS AND DESIGNS INSIDE A MILITARY AIRCRAFT

The immediate and unlimited access to the actual complete electronic market with its very fast technological progress of electronic components, Printed Circuit Board layouts, computer architecture, SW design and IT aspects allows:

* a fast and flexible improvement of mission capabilities,
* an avionics mass and volume reduction (mission performance),
* an avionics upgrade cost reduction,
* an avionics Life Cycle Cost reduction,
* an extended competition,
* a development time and qualification test reduction,
* a extended use of complete off the shelf HW and SW solutions,
* an increase of cross-usability of HW & SW in different products and programmes,
* a solution for the obsolescence difficulties in military programmes.

3. ACTUAL ENVIROMNENTAL REQUIREMENTS FOR MILITARY AVIONICS

Following examples of quantified environmental requirements are actual typical for military avionics:

Temperature:	Operating:	- 40° to +70°C
	Non-Operating:	- 60° to +90°C
	T-Changes:	up to 40 K/s
	Supply air:	-40° to +54°C with 3.5kg/kW/min
Pressure:		3 to 115 kPaa
Pressure Changes:		6 kPa/s increasing
		4 kPa/s decreasing
Humidity:	absolute	0 to 30 g_{WATER}/kg_{AIR}
	relative	0 to 100 %
Sand / Dust:		up to 20 g/m³
Vibration:	Functional:	up to 0.10 g²/Hz
	Endurance:	up to 0.42 g²/Hz
	Frequencies:	10 to 2000 Hz
Acceleration:		up to 13 gn
Acoustic Noise:		up to 150 dB
EMC:	EMC:	> 200 V/m
	NEMP:	> 50 kV/m in ns, 50 A
	Lightning:	> 10 kA
Power Supply:	115/200 V ± 10% , 400 Hz ± 5%	
Power Interrupts:		up to 30 ms

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4. ACCEPTABLE ENVIRONMENTAL CONDITIONS FOR NOT RUGGID, UNSCREENED CIVIL ELECTRONIC COMPONENTS AND DESIGNS

Following examples of quantified environmental conditions are accepted by not ruggid, unscreened civil electronic components and designs:

Temperature:	Operating:	+10° to +30°C
	Non-Operating:	0° to +70°C
	T-Changes:	no data found
	Supply air:	0° to +55°C with 1.5 m/s
Pressure:		70 to 115 kPaa
Pressure Changes:		no data found
Humidity:	absolute	no data found
	relative	0 to 50 %
Sand / Dust:		clean environment
Vibration:	Functional:	up to 0.002 g^2/Hz
	Endurance:	no data found
	Frequencies:	5 to 500 Hz
Acceleration:		up to 4 gn
Acoustic Noise:		no data found
EMC:	EMC:	3 V/m
	NEMP/Lighting:	no data found
Power Supply:	220 V ± 10%, 50 Hz ± 3%	
Power Interrupts:		no interrupts accepted

The comparison of the actual military environmental requirements with those of civil electronic components and designs show significant discrepancies.

If not-ruggid, unscreened civil electronic components and designs shall be used inside military avionics, the military aircraft has to be adapted.

5. ADAPTATION OF MILITARY AIRCRAFT TO THE NEEDS OF NOT-RUGGID, UNSCREENED CIVIL ELECTRONIC IN MILITARY AVIONIC

5.1 MILITARY AIRCRAFT ASPECTS, WHICH INFLUENCE THE ENVIRONMENTAL CONDITIONS OF MILITARY AVIONICS

Following military general aircraft systems have an interface to avionics systems.

* Environmental Control System
* Electrical Power Generation and Distribution System
* Data Link
* Mechanical Integration (Aircraft Structure, Avionics Racks, Module Housing)

Following further logistical aspects influence the environment of the military avionics

* Handling and Maintenance concept
* Testability concept
* Storage concept
* Aircraft Ground Equipment

5.2 ENVIRONMENTAL RESPONSIBILITIES

These interfaces and aspects influence the environmental conditions of the military avionics in the following ways:

The *Environmental Control System* influences the Temperature, Temperature Changes, Pressure, Pressure Changes, Humidity, Contamination, Fungus, Salt Fog, Sand and Dust conditions around military avionics if electrical power is available.

The *Electrical Power Generation and Distribution System* influences the Electrical Supply and EMC conditions for military avionics.
The *Data Links influence also the* EMC.

The *Mechanical Integration* of avionics into the military aircraft influences mainly the Vibration, Acceleration, Shock, Temperature, Temperature Change, Pressure, Pressure Change, Humidity, Contamination, Fungus, Salt Fog, Sand, Dust and EMC conditions of these avionics.

The *Logistical Aspects* like ground support, maintenance, testing, handling, transport and storage have also an effect on environmental conditions like Vibration, Acceleration, Shock, Temperature, Temperature Changes, Pressure, Pressure Changes and Humidity.

5.3 POSSIBLE IMPROVEMENTS OF THE ENVIRONMENTAL CONDITIONS FOR THE MILITARY AVIONICS

In this chapter some examples will be described how the environmental conditions for the military avionics can be improved:

5.3.1 ENVIRONMENTAL CONTROL SYSTEM

Most of the actual produced military aircraft use an Environmental Control System (ECS) based on an engine bleed air, bootstrap, open air cycle and emergency/ground fan air supply concept.

The basics of this technology were developed nearly half a century ago and fit at this time quite well in the overall aircraft concept. Although the efficiency of this concept is very low, requires a lot of engine trust, causing high aerodynamic drag, radar reflections and additional infrared signatures as well as high temperature / high pressure air leakage risks, it seems to be relatively reliable and light.

This concept provides the military avionics during aircraft ground and main ECS failure conditions with unfiltered and unconditioned aircraft ambient air and during normal ECS operation with unfiltered, partly dehumidified engine or Auxiliary Power Unit (APU) bleed air.

To keep the above mentioned, significant disadvantages as low as possible, these type of ECS were designed to provide just an environment which allows high ruggidised military avionics to survive.

New technologies, in development by EADS Military Aircraft Business Unit in Germany, would allow to design an electrical driven, fuel cooled, closed loop vapour cycle system with much higher efficiency, lower aerodynamic drag, lower signatures, but equivalent reliability and mass.

This concept allows significant improved avionics conditioning, *regarding Temperature, Temperature Changes, Pressure, Pressure Changes, Humidity, Contamination, Fungus, Salt Fog, Sand and Dust,* on ground, in flight and in most of the emergency cases.

5.3.2 ELECTROMAGNETIC COMPATIBILITY (EMC)

A survey of the Electromagnetic Compatibility (EMC) problems to be solved for military systems/equipment is presented in figure 1.

As an absolute preposition the "Internal EMC" has to be guaranteed between all electrical/electronic components installed. Care has to be taken about unwanted radiated and conductive coupling between the different components.

Equipment, which will be integrated into a system, has to fulfil "Intra-System EMC"-requirements. Unwanted emissions have to be limited to tolerable levels. Certain immunities are required to avoid interference caused by other equipment. Radiated coupling paths have to be considered as well as conductive ones. Different types of signals must be taken into consideration starting at short time duration pulses up to continuous wave signals.

Most systems have to operate in a certain electromagnetic field strength environment, which might be generated by the transmitters of other systems or also by external broadcast or radar transmitters. "Inter-System EMC" has to be achieved in such a case. - The environment requirements might reach several 100 V/m up to several kV/m in the case of an aircraft. Simple commercial equipment like e.g. computers have to be protected against an environment up to 3 V/m only. - The electromagnetic environment might affect the electrical components either by penetrating the equipment case or/and by inducing currents on the power and signal lines.

Many equipment have to be protected against lightning strikes. "Direct Effects" caused by direct lightning hits might not be of interest in the most cases. The "Indirect Effects" of lightning, however, have to be considered. Significant currents can be induced in the power and signal lines. In the aircraft e.g. levels up to several kA can have been measured. Similar amplitudes can be expected for equipment installed in buildings.

The "Nuclear Electromagnetic Pulse" (NEMP) has to be considered as a problem, too, for many military systems/equipment. The threat level is defined as 50 kV/m with a rise time of a few ns. The NEMP might affect the electronic components in the equipment via the currents induced in the lines and via the fields penetrating directly through equipment case.

For a selected group of systems/equipment TEMPEST is required. If classified information is handled in a system, it has to be avoided, that the non-encoded electrical signals radiate to the outside.

TREE = "Transient Radiation Effects on Electronic" does not belong directly to the electromagnetic effects. It has, however, to be considered in this context, too. Interference or also damage can be caused in electrical circuits by nuclear radiation directly affecting the semiconductor components.

Comparison Between Military and Commercial Requirements

Table 2 presents a survey about the military and commercial requirements on equipment/systems.

"Internal EMC" between all components installed within an equipment is absolutely required in both cases. There is not a real difference between both sides. Solutions can be realised by e.g. a good EMC-design of the Printed Circuit Boards (PCB`s) and a good de-coupling between the PCB`s in the case ("arrangement, special internal shielding, etc.).

"Intra-System EMC" is not too much different between the commercial and the military side, too. Although different specifications are applied in the commercial and the military world including different procedures and limits, the problems are comparable.

"Inter-System EMC" has to cover generally significantly higher environment requirements in the case of military applications. That means, higher field strength levels have to be considered penetrating equipment cases and higher currents induced on cabling. Additional protection is required.

The problems of "Indirect Effects of Lightning" are similar for military and commercial equipment/systems.

The NEMP is a threat, which is mainly considered for military systems/equipment only. The equipment will be affected via the same coupling paths like considered for the "Inter-System EMC". High amplitude field pulses might penetrate via the equipment cases. High currents ("damped sinusoidal signals") might be induced on the lines. Additional protection is required.

TEMPEST is only applicable for selected military systems/equipment. Emissions caused by the non-encoded classified signals have to be controlled very carefully by measures within and outside the equipment. Significant additional protection measures are required.

TREE is also applicable for some selected military systems/equipment only. Some protection measures can be realised by circuit design, but in general special hardened components should be required.

Survey of Additional Protection Measures Required

Commercial components can be considered to have very similar EMC properties (emissions and susceptibility to interference signals) like the military ones. The only exception is TREE. Commercial components should generally be weaker, because hardening against nuclear radiation requires a component special design. In addition the relevant hardening data are not available for the commercial components.
The consequences for application of commercial components in military equipment/systems are :
If TREE requirements exist, commercial components might cause problems. A lot of statistical test data have to be collected to get sufficient confidence about the hardening level and to demonstrate sufficient protection.
If commercial components shall be applied in all other systems/equipment, there should not be any problem, if the EMC design of the equipment/system follows the usual military guidelines.
Designing the equipment/systems following the commercial rules only, has to be considered to be not sufficient. To cover especially the additional "Inter-System EMC"- and NEMP-aspects, the following additional protection measures are required (figure 3) :

- Improvement of shielding of the equipment case against "Inter-System EMC" – and NEMP – fields to be achieved by :

  - Good electrical sealing between cover and case and different parts of the case
  - Grounding of all mechanical introductions (e.g. also wave guides)directly to equipment case
  - Filtering of all unshielded wires (e.g. power lines) running into the case
  - Avoidance/reduction of openings respectively replacement of large openings by a lot of smaller ones
- Additional interface protection measures against "Inter-System EMC"- and NEMP induced currents
  Filters will help to reduce the CW-signals, suppressor diodes to reduce the NEMP induced signals
- Additional cable shielding against the "Inter-System EMC"- and NEMP induced currents
  A single cable shield, e.g. will reduce the induced currents by a factor of at least 10

TEMPEST might require more intensive protection than "Inter-System EMC" and NEMP. This, however, can also be realised on circuit design-, equipment case- and cabling level and does not exclude the application of commercial components.

5.3.3 VIBRATION

Avionics in actual military aircraft has to cope with a relative high vibration load, which is critical for the sensitive commercial electronic and optical components.

A fixed installation of an avionics box would guarantee stable position of the box, but all occurring vibrations would be transferred directly and unlimited to the sensitive components.

A soft installation on passive vibration dampers, like shock absorbers, would reduce the vibration loads, but with high frequency damping the amplitude of movement due to resonant frequencies would increase.

A combination of passive vibration dampers for high frequencies with an active, adaptive damping for low frequencies showed significant reduction of vibration loads on avionics boxes (see figure 4).

The active and adaptive dampers – e.g. two-axis, electromagnetic linear motors - induce forces with 180° phase-shift (see figure 5) to the vibration loads, which lead to a reduction of the amplitudes.

6. RESUME

The military aircraft would profit from an unlimited application of unscreened, not-ruggid electronic components and design. The environment inside a military aircraft has to be improved to allow reliable use of these components and design. There are technical solutions available to fulfil the environmental requirements of these components and designs. Experimental studies would help to prove this new concept.

7. ABBREVIATIONS

A	Ampere
APU	Auxiliary Power Unit
COTS	Commercial Off The Shelf
CW	
EADS	European Aeronautics, Defense and Space Company
ECS	Environmental Control System
EMC	Electromagnetic Compatibility
g	Gravitational Force [9.81 m/s²]
HW	Hardware
IMA	Integrated Modular Avionics
IT	Information Technology
JTA	Joint Technical Architecture
kA	Kilo-Ampere
kPa	Kilo-Pascal
kV	Kilo-Volt
LCC	Life Cycle Costs
m	Meter
MABU	Military Aircraft Business Unit
NEMP	Nuclear Electromagnetic Pulse
p	Pressure [kPa]
PCB	Printed Circuit Board
SW	Software
T	Temperature [°C]
TREE	Transient Radiation Effects on Electronic
V	Volt

8. LITERATURE

[1] EADS (M) Germany Studies “High Performance Environmental Control and Fuel Systems”, 1996 - 2000

[2] EADS (M) Germany Studies “Adaptive Vibration Damping”, 1997 – 2000

[3] EADS (M) Germany Studies “Advanced Cooling and Thermal Design of Avionics”

[4] EADS (M) Germany / Sextant Avionique Valence Technology Proposal “Environmental Conditions for COTS Components in Modular Avionics (ECOMA)”, December 1999.

9. FIGURES

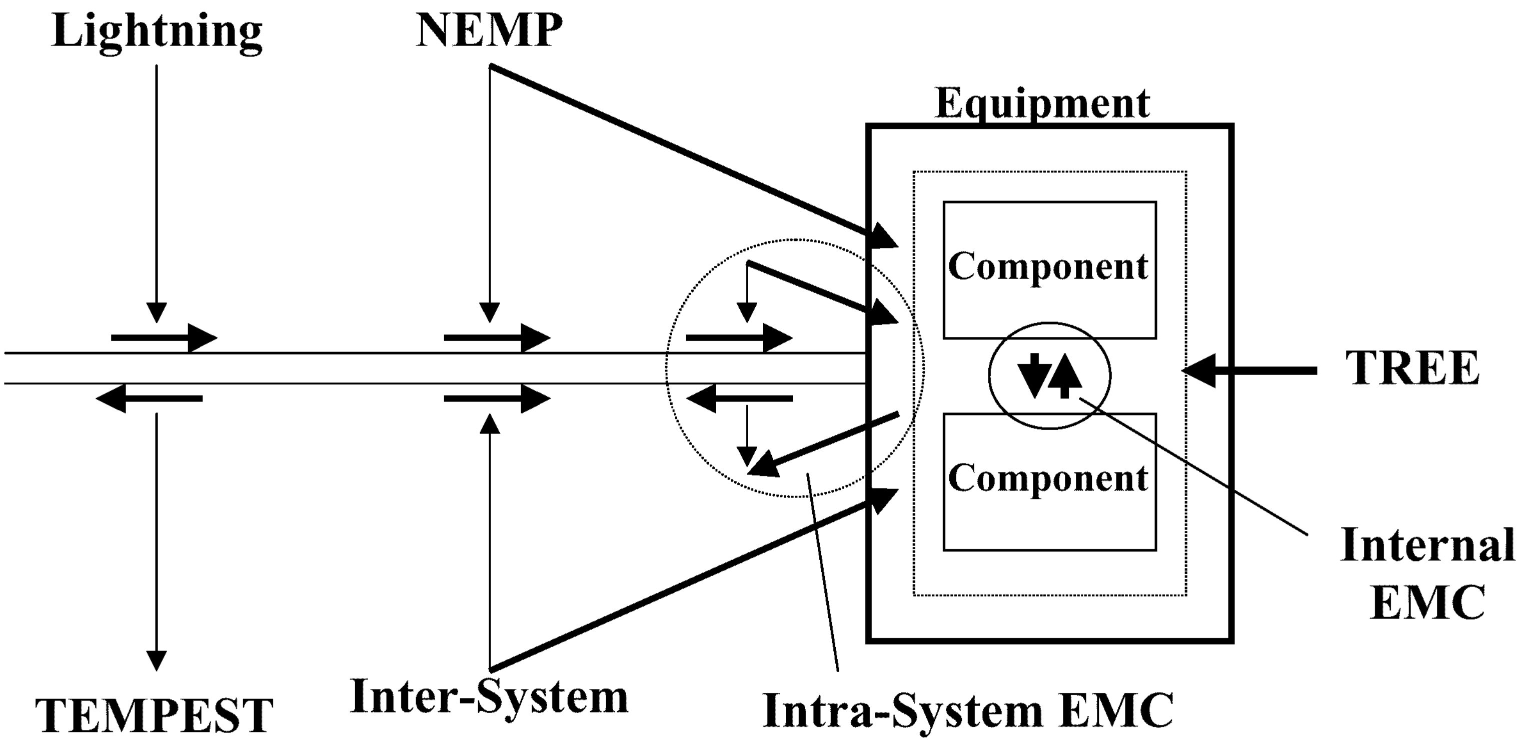


Fig. 1 : Survey of EMC Requirements for Military Equipment/Systems

Field	Requirements		Remarks
	Military Application	Commercial Application	
Internal EMC	Yes	Yes	Absolute preposition; similar problems
Intra-System EMC	Yes	Yes	Other specifications; similar problems
Inter-System EMC	Yes	Yes	In general significantly higher requirements on military side; additional protection required : Case shielding; interface protection : filters, cable shielding)
Lightning Protection (Indirect Effects)	Yes	Yes	Similar problems to be solved
NEMP	Yes	No	Additional requirement, which requires additional protection measures : Case shielding; interfaces : filters, suppressors; cable shielding
TEMPEST	Yes (Selected cases)	No	Additional protection measures required; additional measures for Inter-System EMC and NEMP not sufficient
TREE	Yes (Selected cases)	No	Additional protection measures required; circuit design very often not sufficient; hardened components required

Fig. 2 : Comparison of Requirements for Military and Commercial Application

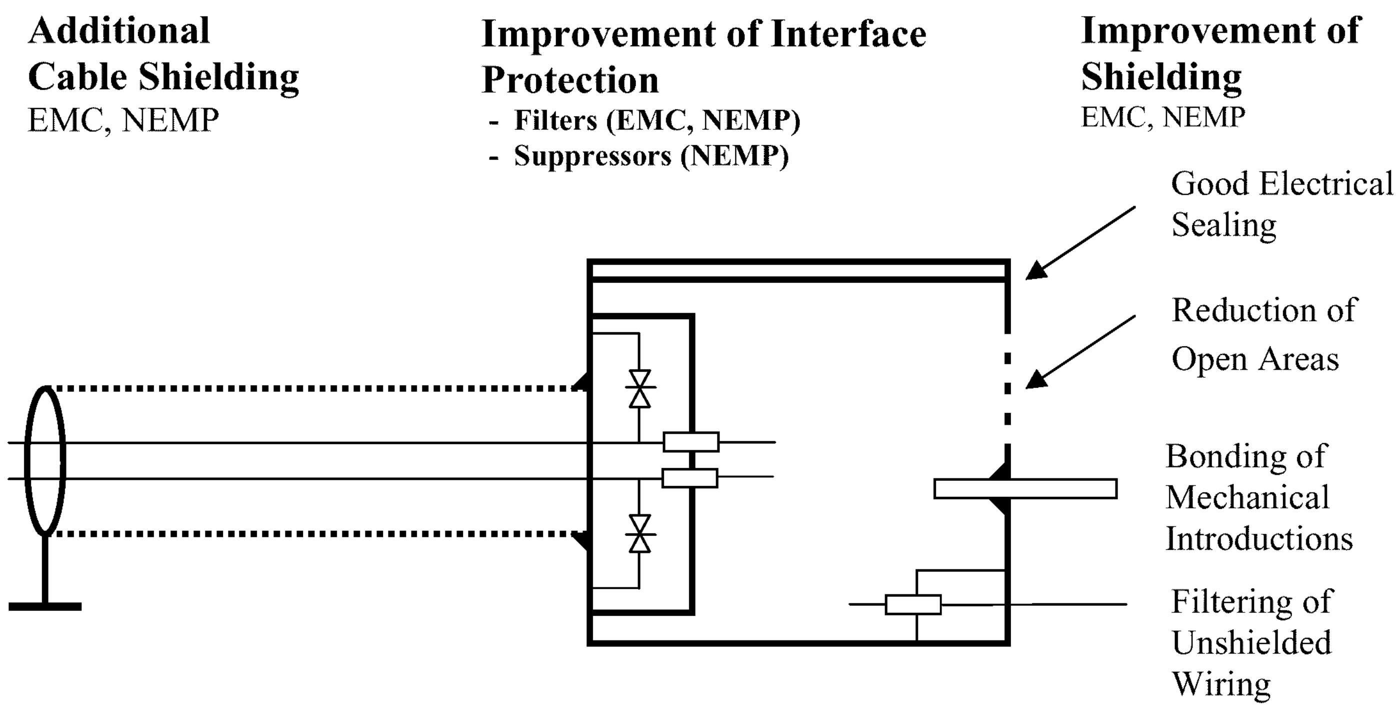
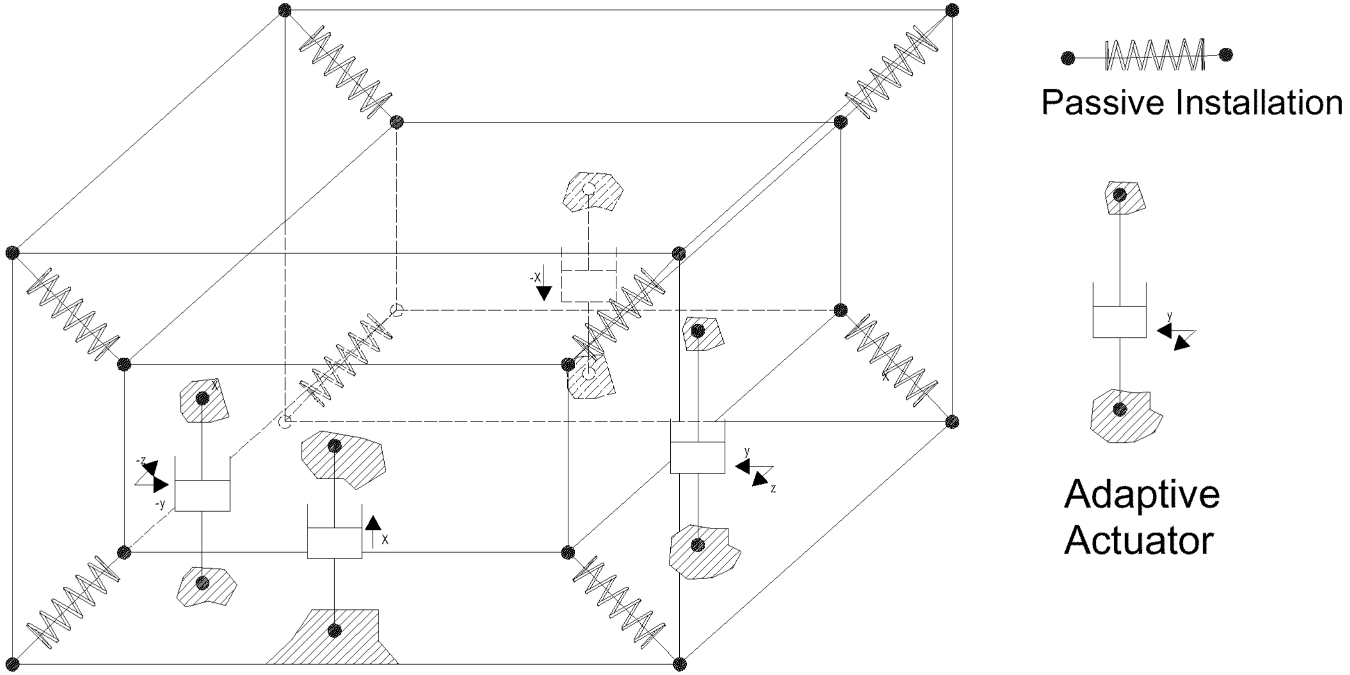


Fig. 3 : Measures to Improve "Inter-System EMC" – and NEMP-Protection

Fig. 4 Active and Adaptive Vibration Dampers:



Schematic of an vibration adaptive Avionics Box Installation

Fig. 5 Vibration Damping - Principal Scheme